Approaches to Manage Temperature Problems

Peter Leinenbach – USEPA

Why temperature?

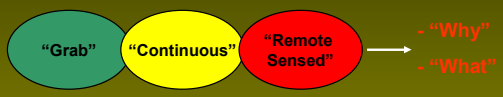
Salmonids - CWA (TMDL) / ESA

Questions to Ask -

- Source Assessment ("Why")
- Management Actions ("What if")
- Evaluate Management ("What")

These issues are addressed through data collection and analysis

Data Needs to Address these Questions



Stream Water Temperature - Defined

Stream Heating Processes

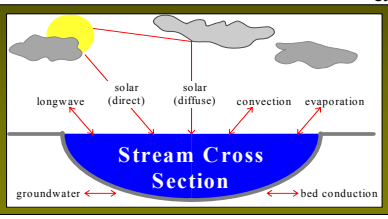
$$\Delta T_w \propto \frac{\Delta \text{Heat Energy}}{\text{Volume}}$$

Stream Water Temperature - Defined

Stream Heating Processes

$$\Delta T_w \propto \frac{\Delta \text{Heat Energy}}{\text{Volume}}$$

Stream Processes that Involve the Transfer of Heat Energy



Net Heat Energy Continuity

$$\Phi_{total} = \Phi_{solar} + \Phi_{longwave} + \Phi_{convection} + \Phi_{evaporation} + \Phi_{streambed} + \Phi_{groundwater}$$

Stream Water Temperature - Defined

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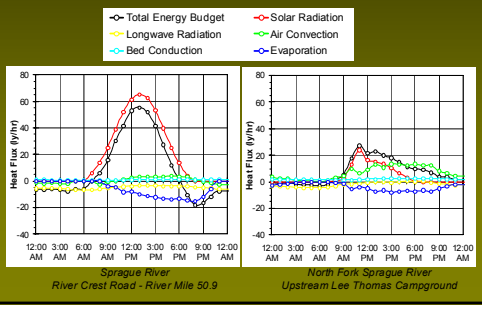
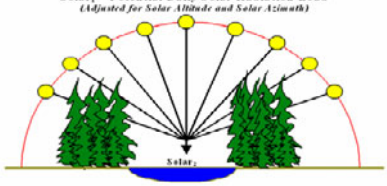


Solar Energy Load Defined As Effective Shade

$Solar_1$ – Potential Daily Solar Radiation Load
(Adjusted for Solar Altitude and Solar Azimuth)



Effective Shade Defined:

$$\text{Effective Shade} = \frac{(Solar_1 - Solar_2)}{Solar_1}$$

Where,

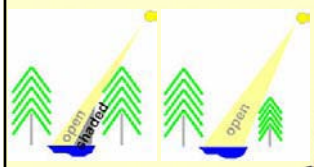
$Solar_1$: Potential Daily Solar Radiation Load
$Solar_2$: Measured Daily Solar Radiation Load at Stream Surface

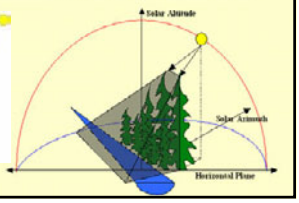
Stream Heating Processes

Factors that Influence Stream Surface Shade

Stream Heating Processes

Description	*Parameter*
	Blue – Not Influenced by Human Activities *Red - Influenced by Human Activities*
Season/Time	Date/Time
Stream Characteristics	Aspect, Channel Width
Geographic Position	Latitude, Longitude
Vegetative Characteristics	Near Stream Vegetation Height, Width, Density
Solar Position	Solar Altitude, Solar Azimuth





Stream Water Temperature - Defined

Stream Heating Processes

$$\Delta T_w \propto \frac{\Delta \text{Heat Energy}}{\text{Volume}}$$

Temperature Patterns are Cumulative

Water Surface

Naturally Occurring Mass Transfer Processes Associated with Stream Networks

Advection Downstream transport associated with flowing water

+ **Dispersion** Turbulent mixing associated with flowing water

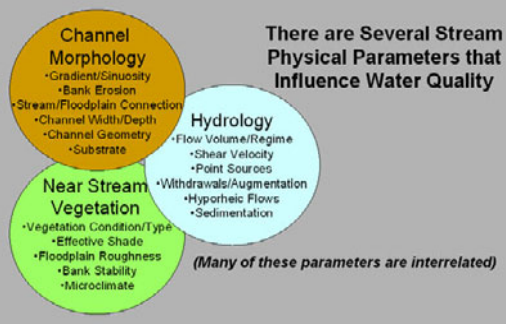
+ **Tributaries** Mixing with other surface waters

+ **Groundwater** Mixing with subsurface waters

Channel Bottom

Stream Heating Processes

Source Assessment

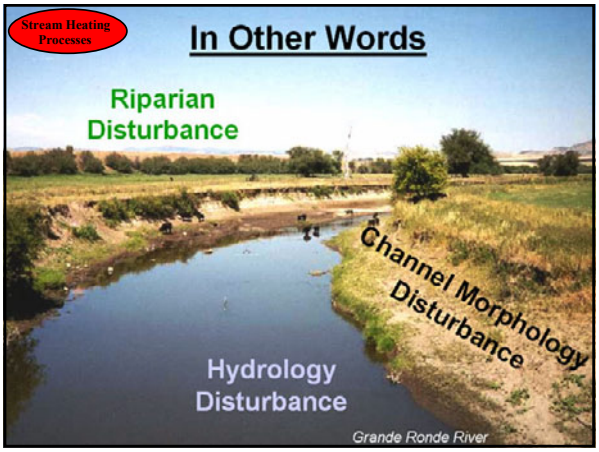


There are Several Stream Physical Parameters that Influence Water Quality

(Many of these parameters are interrelated)

Stream Heating Processes

In Other Words



(Recent) History of Temperature Monitoring Devises

Hand-Held Thermometer

Temperature Monitoring

(Recent) History of Temperature Monitoring Devises

Hand-Held Thermometer

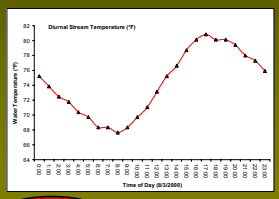
In-Situ Temperature Probe

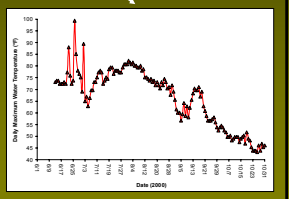
Temperature Monitoring

(Recent) History of Temperature Monitoring Devices

Hand-Held Thermometer

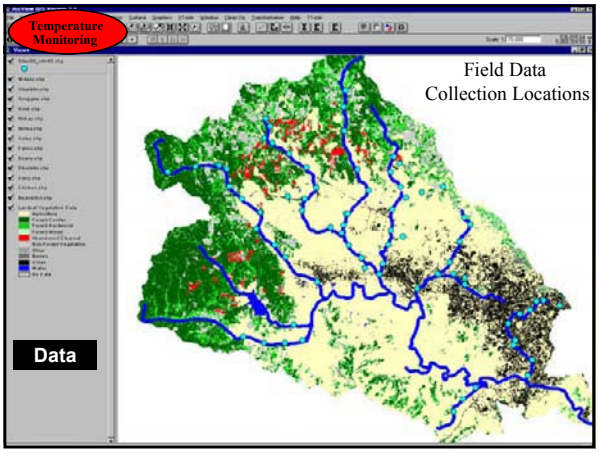
In-Situ Temperature Probe



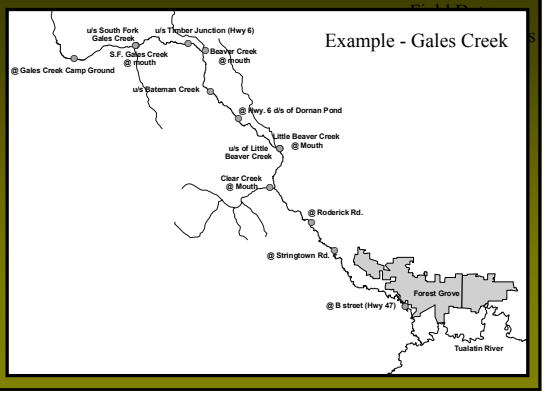


Temperature Monitoring

Temperature Monitoring

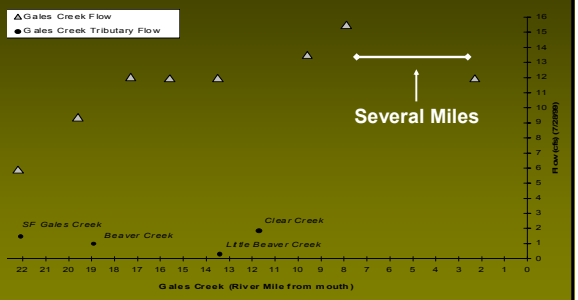


Temperature Monitoring



Temperature Monitoring

Spatial Limitation

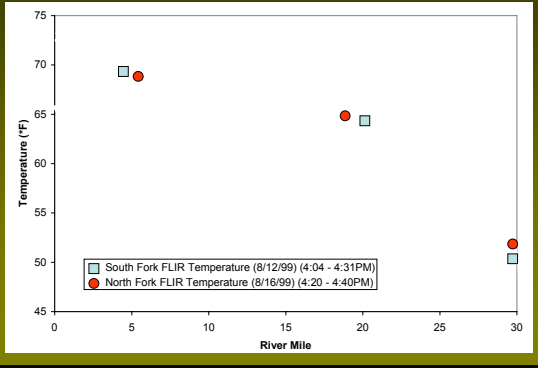


Temperature Monitoring

Spatial Variability *- Upper Klamath Lake Basin – 8/99*

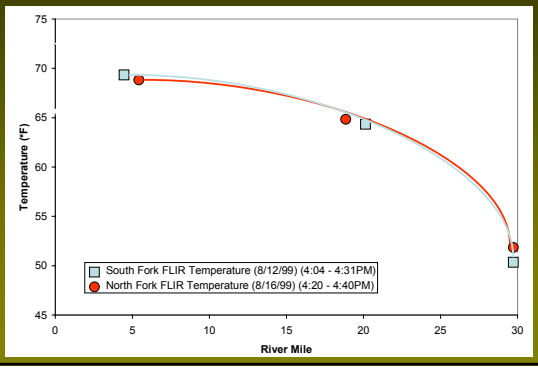
Temperature Monitoring

Spatial Variability – *Only Evaluate what you measure!*



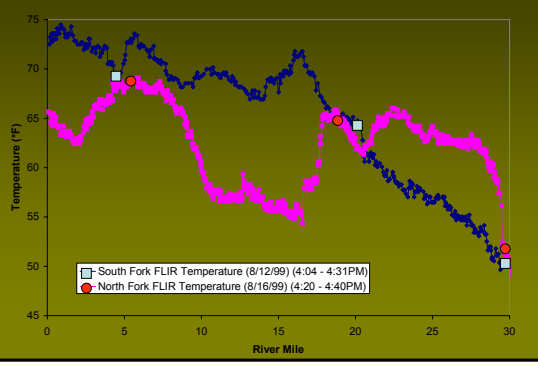
Temperature Monitoring

Spatial Variability – *Only Evaluate what you measure!*



Temperature Monitoring

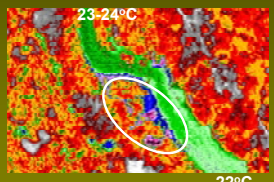
Spatial Variability – *Only Evaluate what you measure!*



Temperature Monitoring

Spatial Variability – *Only Evaluate what you measure!*

Temperature Monitoring



Surface Temperatures (°C)

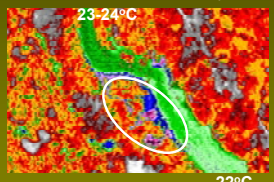
>50	30-50	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	<15

Temperature Monitoring

Remote Sensed Temperature Data

Understand Temperature Processes

- Spatial Temperature Pattern
- Groundwater Influences
- Tributary Influences
- Floodplain Connectivity Influences



Surface Temperatures (°C)

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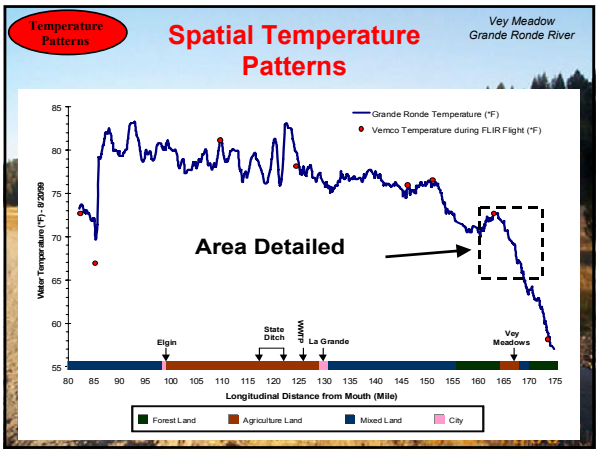
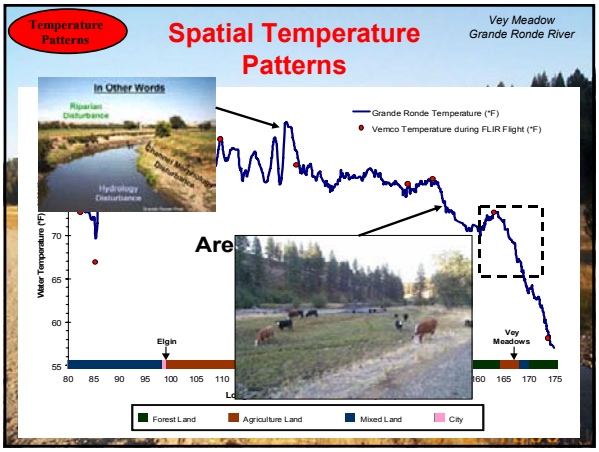
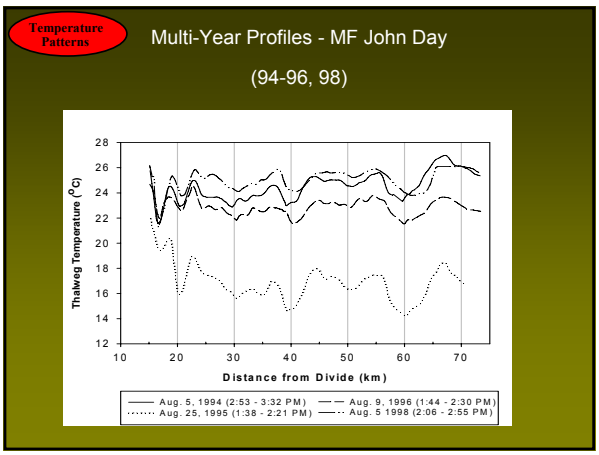
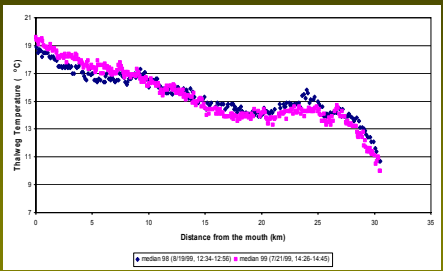

Temperature Patterns
Spatial Temperature Patterns
Vey Meadow
Grande Ronde River
Grande Ronde Temperature (°F)
Vemco Temperature during FLIR Flight (°F)
Area Detailed
Water Temperature (°F) - 8/22/89
Elgin
State Ditch
WWTP
La Grande
Vey Meadows
Longitudinal Distance from Mouth (Mile)
Forest Land
Agriculture Land
Mixed Land
City


Temperature Patterns
Spatial Temperature Patterns
Vey Meadow
Grande Ronde River
In Other Words
Riparian Disturbance
Hydrology Disturbance
Grande Ronde Temperature (°F)
Vemco Temperature during FLIR Flight (°F)
Are
Water Temperature (°F)
Elgin
Vey Meadows
Forest Land
Agriculture Land
Mixed Land
City


Temperature Patterns
Multi-Year Profiles - MF John Day
(94-96, 98)
Thalweg Temperature (°C)
Distance from Divide (km)
Aug. 5, 1994 (2:53 - 3:32 PM)
Aug. 25, 1995 (1:38 - 2:21 PM)
Aug. 9, 1996 (1:44 - 2:30 PM)
Aug. 5 1998 (2:06 - 2:55 PM)

Temperature Patterns

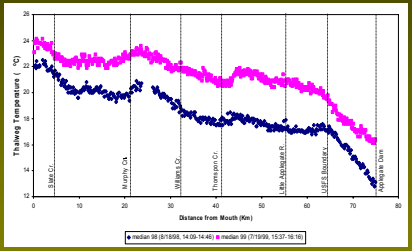
Longitudinal Profile (98, 99)
Little Applegate River



Rogue River National Forest
Applegate Watershed Council

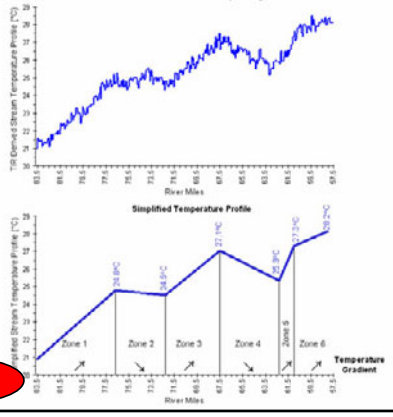
Temperature Patterns

Longitudinal Profile (98, 99)
Applegate River, OR

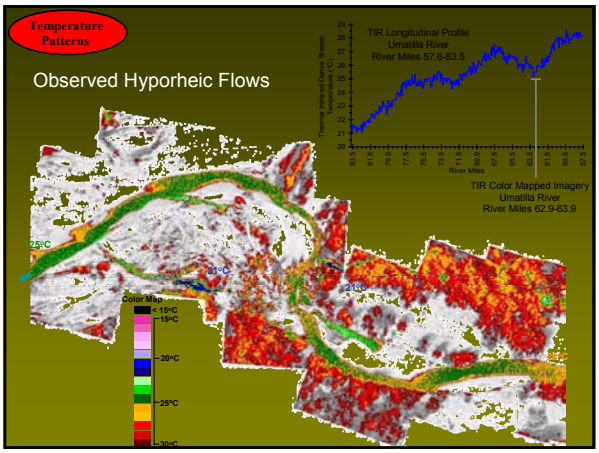


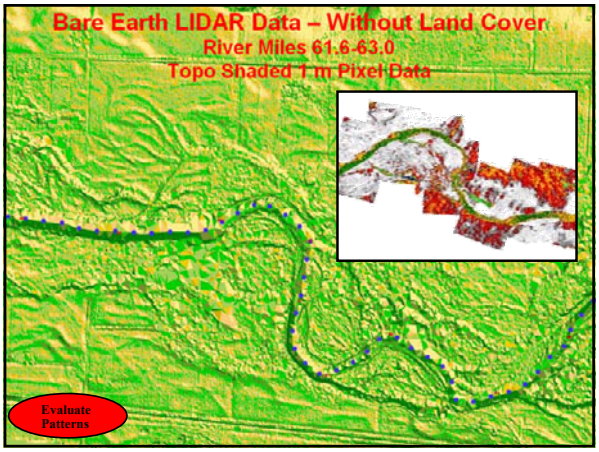
Rogue River National Forest
Applegate Watershed Council

Thermal Infrared Radiometer Data (August 20, 1999 ~ 3:00 PM)

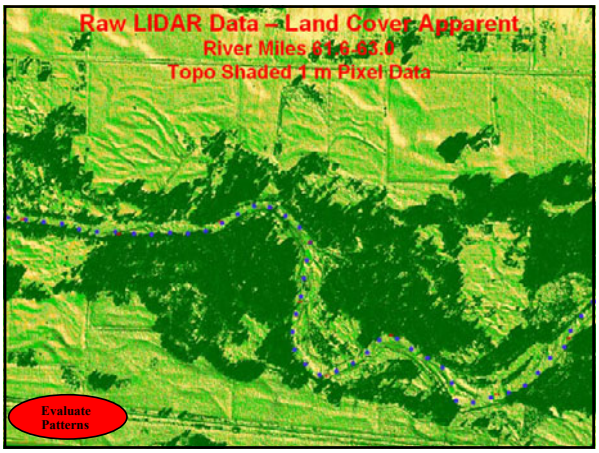


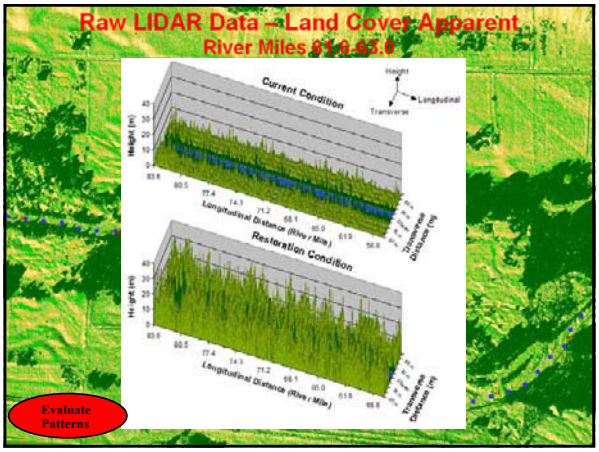
Temperature Patterns

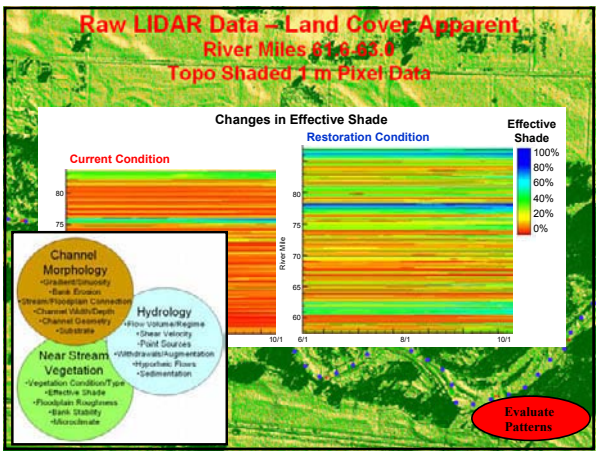

Temperature Patterns
Observed Hyporheic Flows
TIR Longitudinal Profile
Umatilla River
River Miles 57.6-83.5
River Miles
TIR Color Mapped Imagery
Umatilla River
River Miles 62.9-63.9
25°C
21°C
21°C
Color Map
< 15°C
15°C
20°C
25°C
30°C

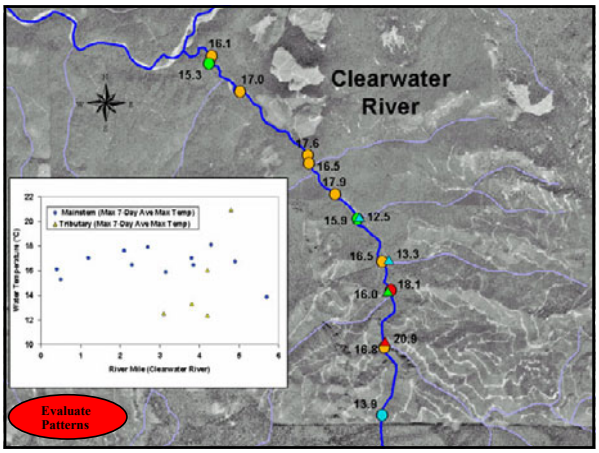

Bare Earth LIDAR Data – Without Land Cover
River Miles 61.6-63.0
Topo Shaded 1 m Pixel Data
Evaluate Patterns

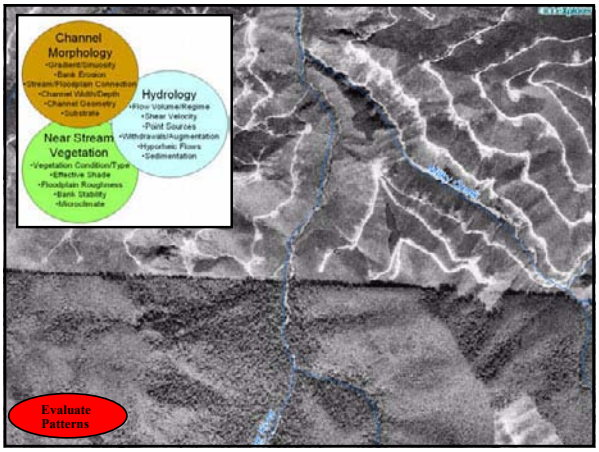
Evaluate Patterns


Raw LIDAR Data – Land Cover Apparent
River Miles 61.0-63.0
Topo Shaded 1 m Pixel Data
Evaluate Patterns


Raw LIDAR Data – Land Cover Apparent
River Miles 61.0-63.0
Current Condition
Restoration Condition
Evaluate Patterns

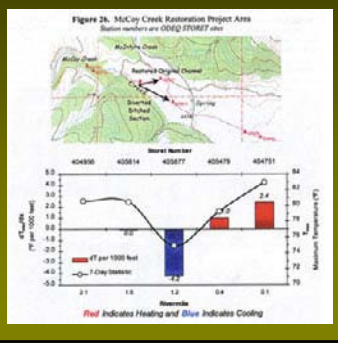

Raw LIDAR Data – Land Cover Apparent
River Miles 61.0-63.0
Topo Shaded 1 m Pixel Data
Changes in Effective Shade
Current Condition
Restoration Condition
Effective Shade
100%
80%
60%
40%
20%
0%
Channel Morphology
Hydrology
Near Stream Vegetation
Evaluate Patterns





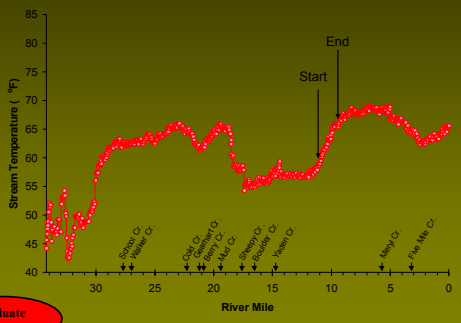
McCoy Creek Restoration – Upper Grande Ronde

McCoy Creek Restoration – Upper Grande Ronde



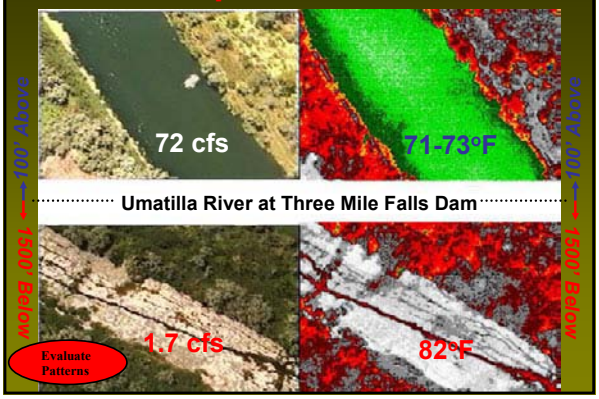
Evaluate Patterns

Hydrologic Condition Assessment
Effects of Water Withdrawal and Return

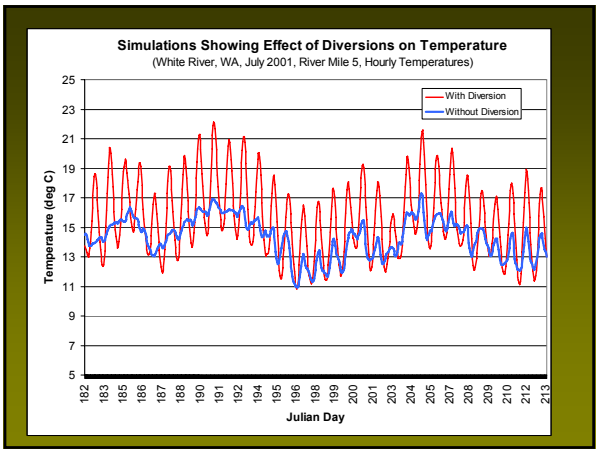


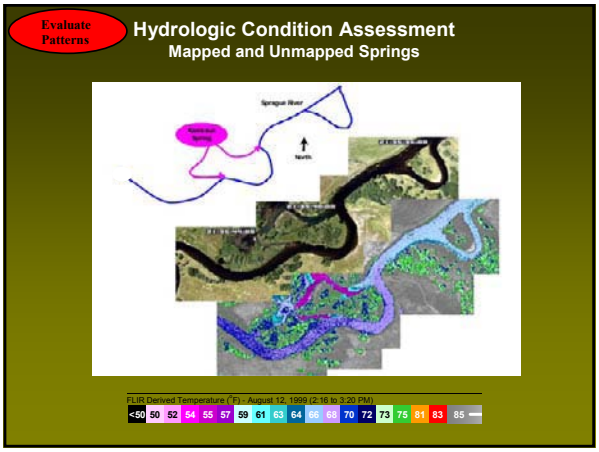
Evaluate Patterns

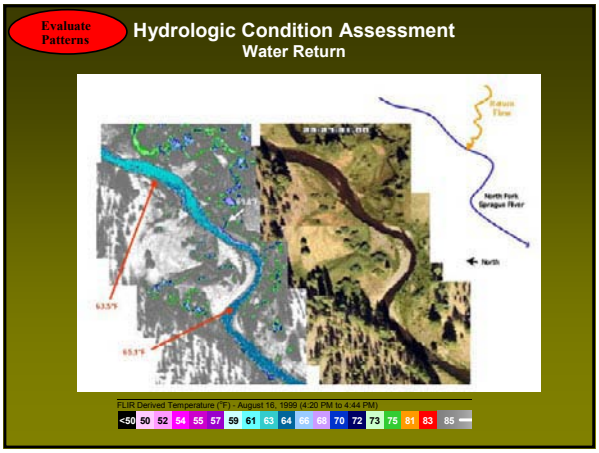
The Importance of Water

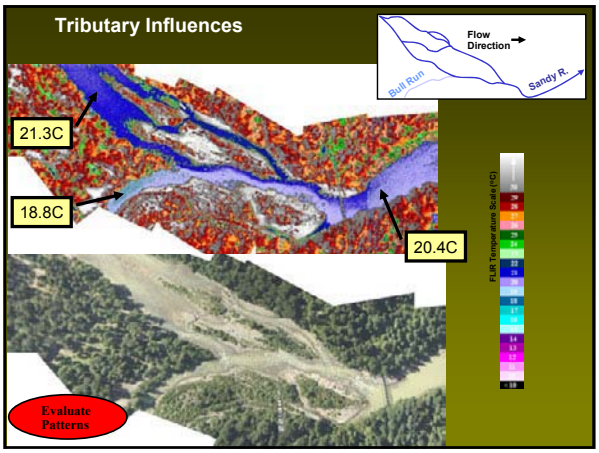


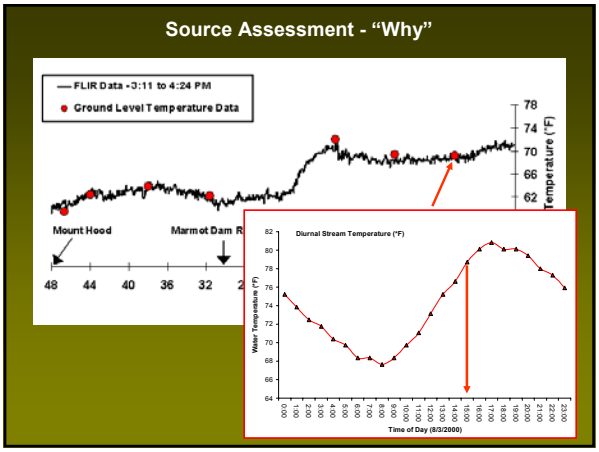
Evaluate Patterns

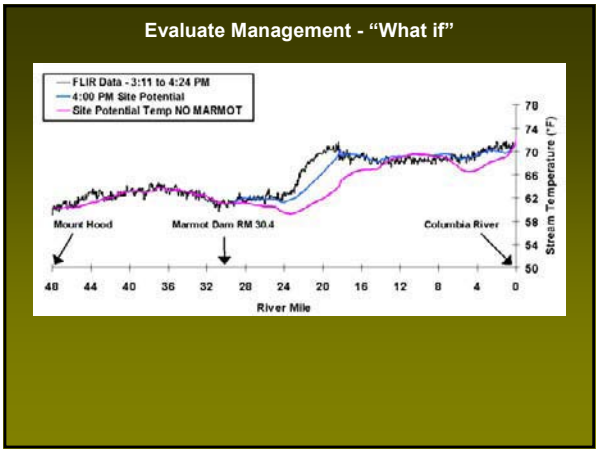

Simulations Showing Effect of Diversions on Temperature
(White River, WA, July 2001, River Mile 5, Hourly Temperatures)
With Diversion
Without Diversion
Temperature (deg C)
Julian Day


Evaluate Patterns
Hydrologic Condition Assessment
Mapped and Unmapped Springs
Sprague River
North
FLIR Derived Temperature (°F) - August 12, 1999 (2:16 to 3:20 PM)
<50 50 52 54 55 57 59 61 63 64 66 68 70 72 73 75 81 83 85


Evaluate Patterns
Hydrologic Condition Assessment
Water Return
Return Flow
North Fork Sprague River
North
FLIR Derived Temperature (°F) - August 16, 1999 (4:20 PM to 4:44 PM)
<50 50 52 54 55 57 59 61 63 64 66 68 70 72 73 75 81 83 85


Tributary Influences
Flow Direction
Bull Run
Sandy R.
21.3C
18.8C
20.4C
FLIR Temperature Scale (°C)
Evaluate Patterns


Source Assessment - "Why"
FLIR Data - 3:11 to 4:24 PM
Ground Level Temperature Data
Temperature (°F)
Mount Hood
Marmot Dam R
Diurnal Stream Temperature (°F)
Water Temperature (°F)
Time of Day (8/3/2000)

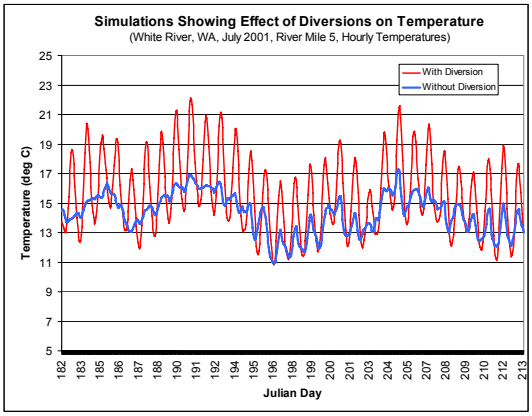

Evaluate Management - "What if"
FLIR Data - 3:11 to 4:24 PM
4:00 PM Site Potential
Site Potential Temp NO MARMOT
Stream Temperature (°F)
Mount Hood
Marmot Dam RM 30.4
Columbia River
River Mile

Summary

- Utilize Local Knowledge
- Evaluate at both Local and Watershed Scales
- Utilize Holistic Approach
  - Flow/Shade/Channel
  - Spatial Patterns

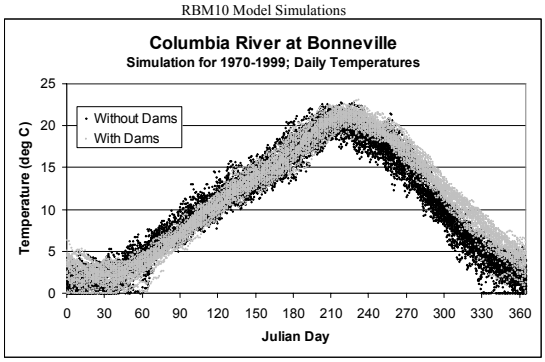
Impacts of Dams on Flowing Rivers

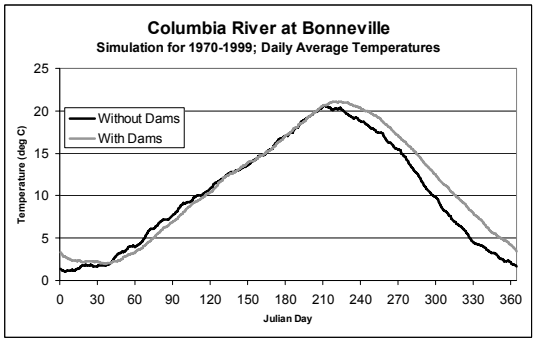
- Stratification - warm surface, cold bottom
- Inundation of local cold water refugia
- Flow augmentation/depletion
  - Effects vary, including
    - cooling effect from Dworshak cold water augmentation
    - warming of diel peak temperature due to White River/Lake Tapps bypass
- Temporal shift in seasonal temperatures
  - Subject of TMDL and FERC studies for a number of rivers, including Columbia, Snake, Willamette, and Deschutes



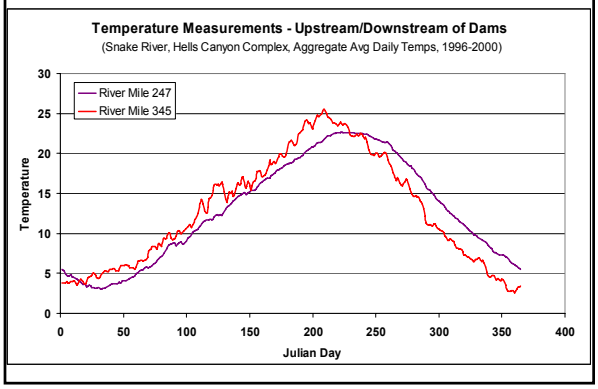
Example of Temporal Shift in Seasonal Temperature

RBM10 Model Simulations

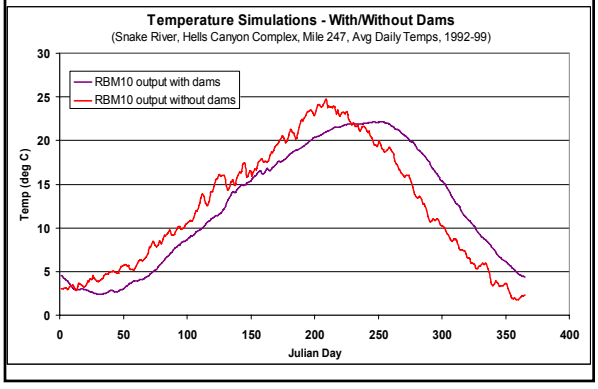




Example of Seasonal Shift Estimated from Measurements



Same River – Shift estimated using RBM10 model



Monitoring Considerations

- Assessing diversion effects
  - Need flow/temperature data above dam and at base of bypass reach at a minimum
- Assessing temporal shift using measurements
  - Comparing apples to apples – mixed temps
    - set upstream station in free-flowing reach
    - set downstream station in tailrace to obtain a mixed temp for comparison to upstream flowing reach
    - need full year of continuous data to assess shift

Commonly Used Models to Evaluate Dam Effects

- **CE-QUAL-W2** (most commonly used in Northwest)
  - Developed by Portland State and Army COE
  - 2D (laterally averaged temperature at a given depth)
  - Includes effects of density and outlet structures on release temps
- **RBM10 and MASS1**
  - Developed by EPA Region 10 and Batelle, respectively
  - 1D (cross sectional average temperature)
  - Used for analysis of Columbia and Snake mainstems
- **EFDC**
  - Developed by EPA contractors (Tetra Tech)
  - 3D (estimates lateral and vertical variation)
  - Used for small scale questions (e.g., confluences, near-dam effects)